IMPERIAL BUREAU OF ANIMAL NUTRITION

Technical Communication No. 7

WHEAT

Pre-Eminence as a Cereal Food; Nutritive Value; Relation to Health and Disease

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WHEAT.

PRE-EMINENCE AS A CEREAL FOOD; NUTRITIVE VALUE; RELATION TO HEALTH AND DISEASE.

I. Human Consumption of Cereals in Early Times and Ascendancy of Wheat as the Principal Bread Grain.

How long man has been consuming wheat as an article of diet is unknown. It appears certain, however, that *Emmer*, the primeval wheat, entered into the food of pre-dynastic Egyptians, and that its importance was certainly not less than that of barley in the diet of the peoples inhabiting the upper reaches of the Nile in those very early times (1, 2 and 3). It is recorded (4) that, next to barley, Emmer was the chief cereal in ancient Babylon (4000 B.C.) down to the beginning of Persian influence over that country. We know also that wheat was cultivated along with millet and barley by the aboriginal Swiss lake-dwellers and by Scandinavian stone-age man; and it is mentioned as one of the principal crops of China five thousand years ago (5).

Immediately prior to the Christian era the chief food grain cultivated in Greece, Italy and in other countries bordering the Mediterranean was barley, but with the gradual spread of wheat from its original home in Western Asia *via* Egypt to Southern Europe there came a growing recognition of its superiority among cereals. In the Græco-Roman period wheat occupied an important place in the economy of advancing civilisations as a food of, especially, the richer classes: in the Rome of Cicero's day, for example, barley was considered fit only for barbarians and slaves, the free citizen spurning all cereals except wheat. Similarly in early Britain, where the principal native crop was oats, the Roman conquest brought about a transition towards wheat cultivation and made Britain one of the principal wheat-exporting countries of the Roman Empire.

Turning from Southern to Northern Europe and to the early conditions prevailing in such countries as Germany, Denmark, Norway,

Sweden, Finland, and Russia we find rye the predominant cereal. Historical references to rye appear much later than to wheat. Apparently unknown to the ancient Babylonians, Egyptians, Chinese and Homeric Greeks, rye must nevertheless have been cultivated by Northern European peoples from a very early date, and it continued to hold an important place in the diet of rural populations in almost all European countries until quite recent times. In some, indeed, it continues in use to the present day, although the statistics covering recent years show everywhere a strong tendency towards reduced human consumption of all other cereals in favour of wheat. Complete transition from oats and rye to wheat did not take place in Britain until the nineteenth century, and in France the peasant classes rarely tasted wheaten bread until after the eighteenth, their principal bread grains at that time being rye and barley.

To look back along the centuries at the changes in cereal cultivation in Europe is to see wheat gradually gaining supremacy over all other cereals. Broadly speaking, there are only two areas left in Europe to-day where cereals other than wheat occupy a position of any importance as human dietary elements. These are the North European region embracing Germany, Denmark, Norway, Sweden, Finland and adjacent countries, where considerable quantities of rye are still consumed, and the southern European countries of Rumania, Bulgaria, Yugoslavia and Greece, where maize is still utilised in the making of bread.

Turning to the New World we find that in Canada and the United States, also, the prominence of wheat is largely a phenomenon of the nineteenth century. In Columbus's time wheat, like most other grain crops, was unknown in North America. The pioneers from Europe who settled in Massachusetts, New York and Delaware first planted rye, the crop to which they had been accustomed in their mother countries, and until the end of the eighteenth century rye was the staple food in many of the American colonies peopled from Europe. But with increasing prosperity rye gave way to wheat, the cultivation of which has spread in the North American continent to such an extent that Europe now largely relies on supplies obtained from there to make up her own deficiencies.

To-day wheat is unquestionably the pre-eminent bread grain of civilised races, and there can be but few parts of the globe with a suitable climate and a sufficient population where wheat is still unknown. A few years ago it was estimated that the number of wheat eaters in

the world was 585,000,000, or more than one-third of the total human population (6). Even in India, Japan and China, where, generally speaking, rice and millet are the principal food grains, there has been apparent in recent years a distinct inclination to an increasing consumption of wheat (7).

To what is this universal appeal of wheat due? Why does man prefer it to the other common cereals, which, as we shall see later, are on the whole nutritionally equal to wheat? The reasons are manifold, but first among them is surely that of taste. Wheaten bread is more palatable to most people than breads made from other grains. This circumstance is due primarily to the unique character of the wheat flour protein, known as gluten, which on the addition of water exhibits the peculiar property of becoming viscid. The viscid substance, or dough, when aerated by yeast fermentation or other process, yields a light, porous mass with sufficient cohesion to prevent collapse—the "bread" of our day. The proteins of barley, rice and oatmeal fail to become viscid with water and are therefore unsuitable for bread-making; the gluten of rye, being of a less tenacious quality than that of wheat, is also not so satisfactory.

Closely associated with the question of taste is that of colour. With the march of progress from primitive to modern conditions there is increasing demand for a bread that is white, not merely on account of its more attractive appearance on the table but also because of its finer texture and superior toasting qualities. Of all flours or meals derived from cereal grains that from wheat is *par excellence* the one from which the whitest bread can be made. In pursuit of this objective the processes of modern milling have been so elaborated as to remove everything that may impart a dark colour to bread and so detract from its appearance, and as a consequence the older methods of stone grinding have gone entirely out of use in all but the most primitive societies.

A noteworthy factor in this increasing preference for wheat is the urge to adopt the manners and customs of those who are considered socially superior. Wheat, being expensive, was at first eaten only by the rich, and its use came quite early to be a mark of aristocracy. With increasing purchasing-power the poorer classes have been able to remove the social stigma attaching to the eating of coarse bread, and their share in the increased consumption of wheat is of the utmost importance.

Although the questions of supply and price are somewhat outside

its scope, the present study of the causes of expanding wheat consumption cannot omit all reference to these major factors. The comparatively stable conditions prevailing in European agriculture at the beginning of the nineteenth century were rudely disturbed by the economic upheaval of the 1870's resulting from the establishment of new and rapid means of communication. The development of railways and the multiplication of steamship routes annihilated distance, made transport cheap and created outlets for the produce of new countries, which became a danger to the European producer. First the United States, then Canada, then Argentina and finally Australia, all having the advantage of fertile lands of unprecedented cheapness, flooded the European market with low-priced wheat. This competition from overseas inevitably led to a fall in values and a glut on the market which was followed by a period of acute agricultural depression lasting almost until the beginning of the present century. One effect of the depression was to accelerate the industrialisation of agriculture and increase the production of cheap wheat. In self-defence peasant farmers forsook traditional methods of reaping, threshing and grinding grain and adopted the new mechanical appliances which were being introduced with astonishing rapidity owing to the severity of competition and the scarcity of labour, which the general current of nineteenth century industrial progress had swept into the towns. All these factors of unlimited supply, low cost, abandonment of primitive customs and urbanisation of populations have contributed in incalculable degree to the increasing consumption of wheat and wheaten bread during the last hundred years.

We have briefly considered the psychological and economic reasons underlying the overwhelming preference for wheat in the human dietary. Let us now judge the matter from a physiological standpoint by examining the nutritive value of wheat in comparison with that of other common cereals. Is there any adequate foundation for the still widely held opinion first expressed by Sir William Crookes (8) in his famous Presidential Address to the British Association in 1892? "We are born wheat-eaters," he said. "Other races, vastly superior to us in numbers, but differing widely in material and intellectual progress, are eaters of maize, rice, millet and other grains; but none of these grains has the food value, the concentrated health-sustaining power of wheat, and it is on this account that the accumulated experience of civilised mankind has set wheat apart as the fit and proper food for the development of muscle and brains."

II. Nutritive Value of Wheat in Comparison with that of Other Cereals.

An estimate of the nutritive value of any food material involves a determination of its content of total nutrients and the losses these sustain in the course of their assimilation by the body. In the following Table the average composition of wheat is compared with that of other common cereals.

Table I.

(For source see Ref. 9.)

	Water.	Protein.	Fat.	Carbo-hydrate.	Cellulose.	Mineral Matter.
Wheat	12·0	11·0	1·7	71·2	2·2	1·9
Oats	10·0	10·9	4·5	59·1	12·0	3·5
Oats (hulled)	6·9	13·0	8·1	68·6	1·3	2·1
Barley	12·3	10·1	1·9	69·5	3·8	2·4
Rye	11·0	10·2	2·3	72·3	2·1	2·1
Maize	12·5	9·7	5·4	68·9	2·0	1·5
Rice with husk	10·5	6·8	1·6	68·1	9·0	4·0
Rice, husk removed	12·0	7·2	2·0	76·8	1·0	1·0
Rice, polished	12·4	6·9	0·4	79·4	0·4	0·5
Millet	12·3	10·4	3·9	68·3	2·9	2·2
Buckwheat	13·0	10·2	2·2	61·3	11·1	2·2

Carbohydrate predominates in all cereals. Protein is somewhat low compared with many other foodstuffs, and as sources of fat and mineral matter cereals are unimportant. Nevertheless the high concentration of nutrients in proportion to bulk and the ease and convenience with which they can be transported and stored place cereals in the front rank of human foods. They form the principal source from which man's energy requirements are met. In view of the preponderance of carbohydrate and the accompanying deficiencies of fat and mineral matter cereals by themselves are imperfect for human needs and must be supplemented with other foods richer in protein, fat, minerals and vitamins in order to make up a well balanced diet. While this general principle applies to all cereals we find, in addition, differences in the degree of deficiency occurring within the individual types. Brief consideration will be given to some of these.

The Protein of Wheat.—Although the protein content of most cereals is approximately the same, namely 10 per cent., it is not necessarily of equal biological value. It would be impossible in this short study to comment in detail on the enormous amount of work which has been done on the biological value of cereal proteins and on the relative nutritional importance of the various amino-acids which compose them. For detailed treatment of the subject the very able reviews by Mitchell (10) and Fixsen (11) should be consulted. Briefly, fundamental experimental work in which pure proteins were fed to rats as the sole source of protein in their diets (these being otherwise adequate), has demonstrated that the *glutenins* of wheat and maize are each capable of meeting the requirements not only of maintenance but also of normal growth. The *gliadin* of wheat, *hordein* of barley and *prolamin* of rye are, on the other hand, incapable of supporting normal growth but sufficient for maintenance ; while the *zein* of maize is insufficient for either maintenance or growth. The failure of zein is ascribed to its lack of the indispensable amino-acids tryptophane and lysine, and the inability of gliadin, hordein and prolamin to support growth is similarly attributed to the absence or insufficiency of lysine in these proteins. Confirmation of this view has been furnished by feeding experiments, in which it was found that the artificial addition of tryptophane made the zein food complete for maintenance, while lysine added to gliadin made the latter adequate for growth.

Investigations in which the various grains themselves have been used to determine comparative protein values have yielded results which are not always easy to reconcile, and much work remains to be done if uncertainties are to be removed. For example, McCollum (12) in one set of experiments, found wheat, maize and rice of equal maintenance value but all inferior to oats or millet, whereas as a result of experiments of longer duration (13) he placed wheat first, then barley and rye, then maize and oats. For the support of growth Osborne and Mendel (14) placed rice in a higher category than oats. Sherman (15) found no material difference between wheat, oats and maize in satisfying the maintenance requirements of adult human subjects, a result which is in agreement with the work of Mitchell (16) and Fixsen (17). Eppelbaum (18) on the other hand found that wheat provided a better source of protein than maize. That qualitative considerations are all-important is further exemplified by the studies of Hermano (19) on rice. He examined five different varieties with protein contents varying from 6·2 to 11·5 per cent. and found that each kind induced

poor growth in rats, the degree of which was unrelated to the percentage of protein in the rice.

Information on the biological value of cereal proteins has also accrued from numerous studies in which cereal flours or the breads baked therefrom have been used. Thus Kon and Markuze (20) found rye bread proteins superior to those of wheat bread. According to van Noorden (21), however, the protein of rye bread is not as readily available as that of wheat bread, although the intestine can be accustomed to it and assimilation then becomes more complete. A parallel to this appears in the work of Lyman (22), who in comparing diets containing white flour and whole wheat found that as time went on the proteins of the flour were less completely digested, whereas in the case of whole wheat a distinct improvement in digestibility was noticeable.

When judging the relative merits and demerits of the protein of different cereals it must not be forgotten that although the zein fraction of maize, for instance, contains neither lysine nor tryptophane the glutelin fraction is as rich in these acids as wheat glutelin, and that the deficiencies of the one fraction are presumably made good by the supplementary action of the other. This consideration also applies in a wider sense and forcibly reminds us of the absurdity in practical dietetics of setting a value on any particular cereal protein without regard for the nutritional quality of the other proteins which make up all well-balanced diets. In practice wheat protein has not been shown to exhibit any special nutritive advantages over the proteins of other cereals in a mixed diet. If, however, as may happen in a vegetarian diet or other exceptional circumstance, the cereal in the diet is important as a source of protein, then wheat is generally regarded as superior to rice, rye and barley, but probably not quite so good as oats. As has already been mentioned, the chief advantage of wheat protein over that of other grains is not nutritional but physical, namely the facility with which a palatable and attractive bread can be made from it.

The Mineral Constituents of Wheat.—Cereal grains contain about 2 per cent. of mineral matter (*vide* Table I). In Table II are set out the percentages of the individual elements present in the whole grains of the commoner varieties.

Potassium and phosphorus are the most abundantly represented and iron the least. Potassium greatly exceeds sodium and magnesium is considerably in excess of calcium. The ratio of calcium to phosphorus is approximately 1 : 10, a proportion not well suited to the

TABLE II.

Average Mineral Composition of Cereals (per cent.)

(For source see Ref. 23.)

	Potassium.	Sodium.	Calcium.	Magnesium.	Phosphorus.	Chlorine.	Sulphur.	Iron.
Wheat (entire) .	0·473	0·039	0·045	0·133	0·423	0·068	0·181	0·0050
Oatmeal . .	0·344	0·062	0·069	0·110	0·392	0·069	0·202	0·0038
Barley (entire) .	0·477	0·076	0·043	0·141	0·400	0·016	0·153	0·0041
Rye (entire) .	0·453	0·035	0·055	0·130	0·385	0·025	0·170	0·0039
Maize (mature) .	0·339	0·036	0·020	0·121	0·283	0·045	0·151	0·0029
Rice (white) .	0·070	0·025	0·009	0·033	0·096	0·054	0·117	0·0009

needs of the animal body, which are best met by foods with a calcium-phosphorus ratio of 1 : 1. Although the figures tabulated above represent the average composition, it must be remembered that the ash content of any cereal will vary with the soil in which it grows and also from variety to variety. Thus Dadswell (24) states that the ash content of wheat grown in Victoria and New South Wales, whilst varying slightly from district to district, is definitely lower than that grown in other parts of the world. Schrumpf-Pierron (25) records the varietal differences found in twelve different wheats grown on the same land near Cairo as follows: K_2O, 0·305–0·490; CaO, 0·057–0·109; MgO, 0·079–0·310; P_2O_5, 0·466–0·728.

The iodine content of cereals has been estimated by numerous investigators and has been found to vary with the source from which the samples were obtained. The figures of Glimm and Halasa (26) may be taken as representative, namely: wheat, 54·4–84·7; rye, 66·5–124; barley, 62–101·3; oats, 60–86·7 γ * per kilogramme. On an average, rye grain contained more iodine than the other cereals. The occurrence of " trace " elements in wheat and wheat flour has been recorded by Sullivan (27), who identified the presence of zinc, manganese, copper, boron, vanadium, cobalt, aluminium and nickel. The distribution of sulphur and phosphorus in different parts of the wheat seed is a matter of some interest in connection with the baking quality of flour. It has been studied by Bertrand and Silberstein (28), and

* γ equals 0·000001 gramme.

also by Feyte (29), who, however, could find no correlation between phosphorus distribution and baking quality. It has been suggested, too, that the form in which phosphorus occurs within the grain is a point of some significance in connection with the production of rickets (30). The phosphorus present in cereals is partly combined with inositol as inositolhexaphosphoric acid, a substance commonly referred to as phytin. Phosphorus in this form is very poorly utilised—a fact which will be referred to later in considering the relation of cereals to disease. Andrews and Bailey (31) estimated that 86 per cent. of the phosphorus in wheat bran was present as phytin.

In considering the distribution of mineral matter in cereals the feature of outstanding importance is the high concentration found both in the outer coat and in the germ or embryo. Table III shows that the bran and germ portions of the wheat seed contain very much more mineral matter than does the floury portion.

TABLE III.

Mineral Composition of Wheat and Wheat Products (per cent.)

(For source see Ref. 23.)

Element.	Whole Wheat.	Wheat Flour.	Wheat Bran.	Wheat Germ.
Potassium . .	0·473	0·115	1·217	0·296
Sodium . . .	0·039	0·060	0·154	0·722
Calcium . .	0·045	0·020	0·120	0·071
Magnesium . .	0·133	0·018	0·511	0·342
Phosphorus . .	0·423	0·092	1·215	1·050
Chlorine . .	0·068	0·074	0·090	0·070
Sulphur . .	0·181	0·177	0·247	0·325
Iron . . .	0·0050	0·0010	0·0078	—

The outer envelope or bran and the germ portion together constitute 15 per cent. of a whole wheat grain, the remainder (85 per cent.) being the endosperm. From the data given it can easily be calculated that more than 50 per cent. of the total mineral matter of a wheat grain is accounted for in the bran and germ. This is a circumstance of considerable practical interest inasmuch as it is just these portions which are removed in the process of milling. In the production of white flour, which is derived solely from the endosperm, more than half of the mineral matter of the wheat grain is discarded.

By many this is regarded as a major argument in favour of the use of whole wheat bread.

No exhaustive review of the literature on the comparative importance of the mineral constituents of cereals and the pros and cons of white *versus* whole-meal bread can be attempted here. In general it is true to say that, as sources of mineral matter, whole wheat, barley, rye and oats are of roughly equivalent value and are all much superior to maize and rice. Advanced civilisations and educated communities, however, normally subsist on a mixed diet which in addition to cereals includes milk, vegetables, fruit, fish and meat. These foods are not only far richer in mineral salts than cereals but contain them in proportions well suited to the body's needs. Hence the question of cereals as a source of mineral supply is one of very little practical bearing. Only under exceptional circumstances, associated, it may be, with a dietary scarcity of milk, fruit and vegetables or with a preponderating consumption of highly-milled cereals such as polished rice, does the matter assume any practical significance.

The Vitamin Content of Wheat.—Cereals have long been recognised as amongst the richest sources of vitamin B. They are also important sources of vitamin E, it now being generally agreed that the oil extracted from wheat germ is the most potent known source of this vitamin. Vitamin A is present in small and unimportant quantities, while vitamins C and D are entirely lacking in cereals.

The most authoritative works on the vitamin B-complex value of cereals and cereal products have been consulted and an attempt has been made in Table IV to collate the available data. In the first three columns numerical relationships given in the literature have been re-expressed and referred to yeast, the richest source, to which an arbitrary value of 100 has been assigned. In the two right-hand columns the well known plus-and-minus sign method of expressing relative potencies is given by way of comparison, vitamin A values being included.

As is the case with mineral matter, it is apparent that the vitamin B of cereals is concentrated in the outer layers of the grain. The high values given for wheat germ, wheat bran and rice polishings are evidence of this. Quite recently a new vitamin B factor, designated B_4, has been isolated from whole wheat. It seems to be concerned with growth and, like the other entities of the vitamin B-complex, is chiefly concentrated in the covering envelope of the seed (34).

It has been mentioned that cereal grains contain no vitamin D. That this is true only in part, however, is shown by the work of

TABLE IV.

Vitamin Values of Cereals and Cereal Products.

Reference:	32.	33.	33.	34.	23.	23.
Vitamin:	B_1.	B_1.	B_2.	B_4.	B-complex.	A.
Yeast . .	100	100	100			
Wheat (whole) .	10	13	5		++	+
,, (bran) .	20			Present in	++	+
,, (germ) .	62	60	15	outer layers	+++	++
,, (flour) .					+ ?	—
Barley . .	10				++	+
Rye . . .	10				++	+
Oatmeal . .	11				++	— to +
Maize (white) .					++	+
,, (yellow) .					++	++
Rice (whole) .	10				++	+
,, (polishings)		53	4·5			
,, (polished) .					—	—
Millet . .	13					

Schittenhelm and Eisler (35), from whose studies on the vitamin D activity of germinated and ungerminated barley it is concluded that, although the dormant grain is inactive, the precursor of vitamin D is present in the ungerminated seed, and that the active substance is formed in the seedling during the course of germination.

Though cereals are not a rich source of vitamin A they certainly contain some. Dangoumau (36), for instance, was able to re-induce growth in rats, whose weight had come to a standstill on a diet deficient in vitamin A, by a daily dose of 0·5–1 c.c. of an ether extract of wheat flour, a characteristic of which was its marked carotene coloration. Whiteside (37) records that flours milled from dry-land wheat are higher in carotene content than flours milled from irrigated-land wheat. Similar observations to the effect that variations in soil-type and manuring may influence the vitamin content of wheat have been made by other workers (38, 39, 40).

As a provider of calories the fat of wheat is of no significance, but the small amount present—chiefly concentrated in the germ—occupies prominence as the carrier of the important vitamin E. Indeed, wheat germ oil, being exceedingly rich in vitamin E, is the principal source from which this vitamin is obtained commercially. It is also known to be present in oats, yellow maize, hemp seed and other grains (41,

42). Vitamin E is a dietary factor essential for normal reproductive function. It is not associated with outward manifestations of disease in the same way as are vitamins A, D, B and C, deficiencies of which lead to keratomalacia, night blindness, rickets, beriberi, pellagra, scurvy and the like. Since its existence was first postulated by Evans and Bishop (43) in 1922 our knowledge concerning vitamin E has been added to by many investigators, a detailed account of whose findings would, however, be out of place here. Their observations, made for the most part on experimental and domestic animals, are mutually confirmatory and show that, with the absence of this vitamin from the diet, normal fertility is impossible in male and female alike. The impairment of the reproductive function can, however, be avoided by appropriate additions to the diet of vitamin E-carrying substances, of which wheat germ oil is that most commonly employed. From chemical data recently published by Biscaro and De Caro (44) it is inferred that wheat germ has a greater nutritive value than maize germ.

Numerous references could be given to the effective use of wheat germ oil in overcoming sterility and other reproductive troubles in farm animals. On the human side, although information is less extensive, there is also much evidence that vitamin E concentrates are finding increased therapeutic employment in conditions of infertility. Thus M'Gonigle (45), describing his nutritional work, mentions the use of wheat germ extract in preventing miscarriage—and incidentally in the treatment of children suffering from thread-worms. Herbrand (46), too, claims that in cases of habitual abortion and in disturbances of menstruation benefit follows the administration of vitamin E in the form of wheat germ oil. The efficacy of "Fertilan," a commercial product prepared from wheat germ oil, is recorded by Vogt-Møller (47), who has successfully used it in the treatment of sterility and habitual abortion in women. So far as our present knowledge goes, however, there is little evidence that vitamin E deficiencies have any widespread practical or economic significance. They have an individual rather than a general application, and do not rank in importance with the classical illustrations of vitamin dificiency, such as beriberi and scurvy. As knowledge advances it may of course be found that the prevalence of sterility among human beings is much more of a nutritional problem than has hitherto been imagined ; but until statistical data accumulate we may dismiss the matter as of secondary importance in our study of the nutritional value of wheat.

We set out to examine whether there is any foundation for the frequently expressed opinion that wheat is more "health-sustaining" than other cereals. If the comparison be made on the basis of identical dietary proportions of the whole grains of either wheat or barley, oats or rye, then no evidence has emerged to justify our placing any one of these in a higher nutritional category than another. To all intents and purposes they are of equal nutritional value. If, however, the comparison be drawn between these four cereals and maize and rice, then the only possible conclusion is that wheat, barley, oats and rye are on the whole superior, the superiority depending on the quality and quantity of their protein and on the amount of mineral matter they contain. With respect to vitamins it is clear that the endosperm of all grains is equally devoid of vitamins B and E, and if one has to choose between the milled flours from any of these grains it is a matter of indifference which is selected, provided the milling in each case has been carried to the same degree of refinement. If on the other hand one compares a highly-milled flour with one of a lesser degree of refinement, whether from the same or some other grain, then the latter will be found nutritionally superior to the former simply because the layers that contain vitamins B and E have not been wholly removed. In other words, the inherent vitamin potency of a whole grain is not transferable to the extracted flour. Untreated cereals have vitamin values approximately equal; treated, their values depend entirely upon the degree of milling. This of course also applies to the mineral elements.

We have already emphasised that wheat is primarily a fuel food, and that where a good mixed diet is ordinarily consumed the protein, mineral and vitamin deficiencies of cereal flours are of no practical account. They are more than made up by the milk, fruit and vegetables which find an important place in ideal human dietaries. Unfortunately conditions are not all ideal. Either ignorance or poverty or a combination of both has led to much that is deplorable in the food habits of certain sections of almost every community. Through indifference to their health value, or on account of their high cost, the "protective" foods do not find the place they should occupy in many everyday dietaries. The alternative is to rely on the cheaper carbohydrate foods such as cereals, excessive consumption of which has adverse effects upon health. Some of the more salient features of this aspect of our study will now be passed under review.

III. Cereal Consumption in Relation to Individual and Public Health, with Special Reference to Wheat.

Beriberi.—It is a universally accepted fact that the primary cause of beriberi is a deficiency of vitamin B in the diet. Beriberi principally occurs among peoples inhabiting tropical countries whose staple article of food is polished rice. Statistics show that the disease is one of the most important causes of death in, for example, Japan, especially during the first year of life, when the death-rate has been as high as 416 per 100,000 (48). Polishing entirely removes the layers containing vitamin B, and the deterioration of the food value of the grain thus brought about is further accentuated inasmuch as the polishing reduces the amounts of manganese, iron and phosphorus to about one-half and of calcium, magnesium and potassium to about one-third of the amounts originally present in the grain (49).

It is now recognised that vitamin B consists of more than one factor. The fractions B_1, B_2, B_4 and B_6 are commonly mentioned in the literature, and deficiency of one or more of these is responsible, apart from the nervous symptoms characteristic of beriberi, for manifestations of metabolic disturbance such as failure of growth, dermatitis, ulcers and other disease conditions. Despite the many efforts to encourage the greater use of unpolished rice in order to minimise the risk of disease the polished variety, largely on account of its greater palatability, still retains its popularity, with the result that beriberi continues to rank as a disease of major importance among rice-eating peoples.

In some countries the encroachment of outside civilising influences has been blamed for the extended use of highly milled cereals in place of more valuable native foods. Strong (50), writing of conditions in the Western Pacific, attributes the high incidence of beriberi among native labourers in Papua to the growing consumption of sago and polished rice. This menace disappeared when one-third of the rice in the ration was replaced by native foods or by coarsely milled wheat flour. In Iceland, too, beriberi has recently made its appearance following the displacement of rye and barley by white wheaten flour and polished rice, accompanied by a decreased use of milk and milk products (51).

Among wheat-eating peoples, however, beriberi does not as a rule occur, and the answer to the question why this should be so lies in the other components of the diet. If rice-eaters in the Orient were to substitute wheat flour for polished rice, without otherwise altering

their diets, beriberi would still occur: but if European and North American peoples were to change over from wheat to polished rice it is unlikely that beriberi would occur to any great extent. This is because, broadly speaking, Western civilisations have a safeguard against vitamin B deficiency in the other components of their diets, namely milk, eggs, fresh vegetables and fruit. This protective advantage must be non-existent where beriberi is endemic, otherwise the disease would not occur.

Scurvy.—Although scurvy, the classical manifestation of vitamin C deficiency, is rare in Western countries cases have been reported from labour camps and among organised workers and others who through neglect are compelled to subsist on imperfect diets composed for the most part of cereals. As cereals contain no vitamin C they are all equally ineffective as anti-scorbutics. Happily the necessity of providing the anti-scorbutic vitamin in the form of lime or other fruit juice is so widely appreciated nowadays that these outbreaks are comparatively infrequent. In default of other sources of vitamin C it is useful to bear in mind that *germinated* cereal grains contain considerable quantities (52, 53).

Pellagra.—Pellagra is a complex degenerative disease characterised by digestive disturbances, muscle weakness, dermatitis, and impairment of the nervous system which may end in insanity. According to Aykroyd (54), from whose excellent review of the subject much of the following information has been borrowed, it is one of the most formidable and deadly of human diseases, and in spite of recent advances remains a public health problem of the most pressing urgency in many countries to-day.

Pellagra is definitely associated with the eating of maize, and in the minds of the majority of investigators the connection between pellagra and maize consumption is indissoluble. It is true that cases have been recorded from among rice, wheat, rye and millet eaters, but these are mostly confined to isolated individuals and their importance pales into insignificance in comparison with the enormous number of pellagrins found in the maize-eating countries of the world. In the southern United States, Rumania, Bulgaria, Yugoslavia, South Russia and Turkestan maize is the staple diet among the rural and poorer classes, and it is just these countries that are most afflicted with the disease.

A veritable army of investigators has endeavoured to explain precisely why maize-eating should be so intimately responsible in the causation of the disease. Papers on the subject abound, and only a

very cursory review of the essential conclusions drawn from all this work can be attempted here.

In view of the fact that substances rich in vitamin B_2 have been shown to prevent pellagra in human beings one line of research has followed the suggestion that the condition is caused by a dietary deficiency of this factor, the inference being that maize contains less of this vitamin than other cereals. Aykroyd (55), however, examined the vitamin B_2 content of common cereals and, ascertaining that rice contained no more than maize, found it difficult to explain why pellagra should be rare among rice-eaters and common among maize-eaters if vitamin B_2 deficiency were the chief ætiological factor. Furthermore, in striking contrast with the circumstances surrounding the causation of beriberi, the degree of milling to which maize may be subjected seems to have little or no bearing upon its pellagra-producing potency. Maize meal, in which the outer vitamin B_2-containing layers of the grain are still retained, has been observed by Aykroyd to be in common daily use in certain Rumanian villages the inhabitants of which are seriously afflicted with the disease.

A second group of workers maintain that it is the inferior quality of the protein in maize which plays the dominant rôle in the development of the disease, although they realise that vitamin B_2 may also have a part inasmuch as most sources of first-class protein are associated with considerable quantities of the B_2 factor. We have already seen that in respect of the biological value of their protein there is little difference between wheat and maize. In view of this the theory that maize protein deficiency is responsible for pellagra is not easily reconciled with the rare occurrence of the disease among peoples whose staple foodstuff is wheat. If protein deficiency is involved one would expect to find considerable prevalence of pellagra among the poverty-stricken classes of wheat-eating countries, whose diets so often consist of bread and margarine with very little meat and vegetables. Such, however, is not the case.

A third group of investigators hold the view that pellagra is caused by a toxic principle present in maize. This theory finds support in the successful therapeutic results which have in some cases followed the administration to pellagrins of substances which, it is suggested, neutralise the effects of the toxin (56). Stockman and Johnston (57), who have closely studied this aspect, report the presence, not only in maize, but also in rye, oats and wheat, of an acidic toxin which proved poisonous to monkeys. In their experiments there was no question of

vitamin deficiency of any kind, for all the experimental animals were abundantly supplied with vitamin-containing foods. As all the cereal grains examined had a poisonous action these workers conclude that the toxin is an entity common to all cereals, a circumstance which would explain why isolated cases of pellagra are occasionally met with among eaters of cereals other than maize. They regard the high incidence of pellagra among maize-eaters as essentially a question of the quantity eaten. These conclusions are of undoubted interest and importance, but it is felt by many that, as pellagra among maize-eaters is so common and among wheat-eaters so exceptional, the toxin theory does not solve the problem unless it can be shown that the toxic principle is far more abundant in maize than in other cereals, and this has not yet been proved.

Whatever further information research may yield, it seems that, for the present at least, a theory which would cover the main facts relating to the ætiology of pellagra is that a toxin exists in maize of which the effects are corrected either by sufficient high-quality protein or by vitamin B_2 or by both these factors acting conjointly (58).

It is interesting to note, on reading through the literature, that in the fight against pellagra the main weapon is the all-round improvement of the dietary, and particularly the replacement of maize by wheat. In Italy, where at one time the menace assumed considerable proportions, there has been a marked decline in the death-rate from pellagra during recent years. The figures quoted by Aykroyd (54) show a diminution from 10·7 per 100,000 in 1900 to 0·2 per 100,000 in 1928. This improvement is largely due to an enlightened public-health programme including, among other things, propaganda against excessive maize consumption, the prohibition of the sale of " spoiled " maize and the establishment of rural bakeries and soup-kitchens with the object of supplying a nutritious diet including wheaten bread. In Rumania, on the other hand, where such intensive measures do not as yet appear to have been adopted, one sees pellagra at its very worst and official statistics reveal no sign of any improvement. In certain areas as many as 10 per cent. of the population suffer from the disease every spring, and the death-rate of 9·0 per 100,000 recorded for 1932 is almost certainly an under-estimate.

Kandelaki (59), describing conditions in the Georgian Soviet Republic, cites a striking example relating to wheat and maize in the ætiology of pellagra. The disease is confined to the maize-eating districts of the Western portion of the Republic. It is not found in East

Georgia, where the staple food is wheat. In his survey only 17 sporadic cases were notified as occurring within the wheat-eating area, all of which, on fuller investigation, were found to refer to individuals who preferred maize to wheat. In Africa the observations of Mitchell (60) on the health of Uganda prisoners revealed that when maize was substituted for potatoes in prison rations 19 cases of pellagra resulted. The outbreak subsided when the diet was again altered to include lean meat, fresh vegetables and germinated beans. The disease is frequently seen among Bantus, who are essentially a maize-eating tribe ; and many natives in Zululand and Transkei are apparently in a sub-pellagrous state for the same reason (61). Turning to Egypt, we find that pellagra is much more noticeable among peasants in the areas where maize is the staple cereal than in Upper Egypt, where maize is replaced by millet, beans, lentils and wheat (62). The mention of millet recalls the prevalence of a condition resembling pellagra among the Arabs in the Butana Desert and in the Anglo-Egyptian Sudan during the hot season when there is little to eat except whole millet. At other seasons milk is available, which tends to mitigate the severity of the trouble (63).

The two outstanding features which emerge from a study of the conditions under which pellagra occurs are the maize-eating itself and the extreme poverty of the maize-eaters. Pellagrins are notoriously poor, and the big difference between rich and poor is that the poor lack the means and opportunity to procure enough of the high-quality foodstuffs which would afford protection even if maize continued as the principal cereal in the diet.

Vitamin A Deficiency ; Toxins in Cereals ; Formation of " Stone " ; Anæmia.—Consideration of the toxin theory demands mention of Mellanby's (64) observations on dogs fed on white maize. These dogs developed nervous lesions closely resembling those seen in pellagra. The lesions could also be reproduced by feeding the animals with ergot ; but when the diet was adequately supplied with vitamin A the symptoms did not appear. It is suggested that these results may help to explain the ætiology of ergotism, lathyrism and other analogous conditions occasionally met with among eaters of ergotised rye, the lathyrus pea, white maize or other cereals under conditions of vitamin A deficiency. Stockman (65), however, refutes this view, as he was able to produce symptoms identical with those found in convulsive ergotism by feeding monkeys on unergotised rye, wheat and other cereals. He concludes that the disease is caused by poisons other than ergot which are normally present in cereal grains, including wheat.

That the consumption of wheat by peoples who are exposed to risk of vitamin A deficiency may have adverse consequences is also emphasised by McCarrison (66). His researches on the formation of urinary calculi are of great practical interest. In India stone in the bladder is most prevalent in the wheat-eating races of the North and relatively rare amongst rice-eaters of the South. In certain of his experiments wheat produced stone in 32 per cent. of rats, millet in 8 per cent. and rice in 9 per cent. A dietary deficiency of vitamin A was partially responsible, but it is suggested that some unknown toxic principle, present presumably in the outer layers of the grain, is also involved. Support is lent to this view by the observation that whole wheat favours stone production much more than does white flour, a fact which, it is held, may be related to the diminished incidence of bladder stone in Europe during the last fifty years (this period coinciding with the increasing use of white flour).

A special type of toxicity in wheat has recently been reported from the United States. This, however, is confined to wheat and other plant foodstuffs grown in certain defined districts, and is apparently due to the presence of selenium in the protein fraction of the grain. This toxic substance, which has been found in maize, wheat, barley and emmer from the affected areas, is responsible for a marked degree of anæmia in experimental animals, resulting in early death (67, 68).

The reference to anæmia recalls the work of Rose and her colleagues (69) on rats which had been rendered anæmic on a milk diet. When the milk diet was supplemented with whole wheat hæmoglobin regeneration took place at a rate proportional to the iron content of the supplement. White flour was less efficient in this respect even when attempts were made to restore it to the original efficacy of whole wheat by the addition of iron and copper. Hence whole wheat appears to contain certain anti-anæmic factors which are lacking in white flour and which cannot be supplied by the mere addition of iron and copper.

Rickets.—In an earlier section of this review reference was made to the high content of phytin in wheat bran and to the fact that phosphorus in this form was not easily absorbed. To this peculiarity is ascribed the rachitogenic action of cereals, because to feed cereals in which a large proportion of the phosphorus exists as the poorly utilisable phytin is in effect to feed a diet low in phosphorus. In cereal diets of high calcium content the rachitogenic action results from faulty phosphorus absorption, while in low-calcium high-phosphorus diets, where calcium is the limiting factor, it is believed that the excess of

phytin interferes with calcium absorption. Although the problem—which incidentally has been dealt with fully by Bruce and Callow (30)—is one which concerns cereals as a group there are several interesting papers with special reference to wheat in this connection which may appropriately be mentioned here.

Rogozinski and Ciechanowska (70) showed that rats fed exclusively on wheat developed typical rickets which could be prevented by the addition to the diet of calcium salts in amounts sufficient to balance the excess phosphorus in the wheat. It is apposite also to refer to the work of Greaves and Greaves (71), who fed two varieties of wheat, one containing 0·080 per cent. calcium and the other 0·055 per cent., to rats for three weeks, the wheat forming 90 per cent. of the ration. At the end of the period the calcium and phosphorus of the bones and blood were higher in the animals fed the first wheat than in those receiving the second. The work of Ranganathan (72) would indicate that among cereals wheat supplies calcium in readily available form. He determined the degree to which rats were able to utilise the calcium and magnesium from cakes made respectively from whole wheat, cambu, cholam, ragi, and polished rice, and found that the best calcium balances were obtained with whole wheat, cholam and polished rice. Positive magnesium balances were obtained only in the rats fed on whole wheat or polished rice.

Wheat Germ and Growth; Whole Meal v. *White Bread.*—Suggestive, too, are the numerous successful results in achieving increased growth in underweight children by the use of wheat and wheat products. Thus Morgan and Barry (73) secured weight increases in children, to whom they had given rolls made from 50 per cent. wheat germ and 50 per cent. white flour, three times as great as in children not so fed. Again, Crimm and his co-workers (74) increased the gain in weight of tuberculous children by giving a special cereal diet which included supplements of wheat germ, yeast and minerals. This has been confirmed by Ross and Summerfeldt (75) and by Hoobler (76), who found that the dietary addition of wheat germ extract stimulated infants to a greater rate of growth in length. These findings also received confirmation from Weston (77), whose studies showed that no benefit accrued to undernourished children by feeding them cereals from which the bran and germ portions had been removed. He obtained a prompt improvement, however, by using a cereal mixture containing 35 per cent. whole wheat, 25 per cent. each of unpolished rice and oats, and 15 per cent. of yellow maize. This mixture, fed to lactating mothers,

produced milk of a higher nutritional value, as reflected in the growth of the young, than that produced by feeding a single-cereal diet.

The beneficial effects on growth which these authors describe are primarily attributable to the vitamin B factor present in the outer layers of the whole grains, and hence many suggestions have been made for incorporating wheat embryo, bran extracts, yeast and other vitamin B rich substances in breads and biscuits intended for the use of children and adults alike. Krogh (78), for instance, proposes the addition to white flour of five times the amount of yeast usually employed in making bread. This, it is claimed, would ensure against the shortage of vitamin B which she regards as of common occurrence in many everyday dietaries in Denmark. Others advocate the use of whole-meal bread or of bread made from flour milled by special processes which have as their object the retention of all the nutritive properties of whole wheat without any of the objectionable features of coarseness and unpalatability. One of the most noteworthy of these processes is that first practised about forty years ago by the German milling engineer Steinmetz. It is known as the " wet decortication " method of flour preparation and has quite recently received renewed attention from Casserman (79), who strongly advocates its revival in the interests of health.

To-day, however, the majority still defend the use of white bread on the ground that its deficiencies can be corrected by the use of other foodstuffs. If wheat germ and bran preparations are necessary, they say, let them be used by themselves, this being preferable to incorporating them in flour. In the opinion of many one of the greatest objections to whole-meal bread is its indigestibility, arising from the high proportion of bran elements which it contains. This is an aspect of the white *versus* whole-meal bread question of which space permits only bare mention. Rationally employed, bran may be an effective source of roughage in a diet ; but the more effective the roughage the more likely it is to provoke disturbances in the alimentary tract, and to most people bran by itself or incorporated in whole-meal bread is less acceptable than the roughage supplied in the fibres of fruits and vegetables.

Wheat Consumption in India in relation to Health.—This survey may fittingly close with a reference to the very important and thought-provoking findings of McCarrison and others in their studies of dietary habits among the peoples of India. No more lucid or instructive account can be given of this work than that recently written by

McCarrison (80) himself, and therefore no apology is made for quoting certain portions *in extenso*.

" Throughout the whole of India (he says) the staple article of diet of the masses is a cereal grain of one kind or another—wheat, barley, millet, maize, rice—sometimes a mixture of two or more of them. Most of these grains are eaten whole ; these are not subjected to any milling or refining process before use. The outer layers of the grain and embryo, containing valuable dietary constituents, are thus consumed with the endosperm. Rice is the single exception to this rule ; though within recent years the use of white flour and white bread is spreading in the larger towns and cities. . . . Biological tests in this [McCarrison's] laboratory have shown that these cereals differ in nutritive value, whole wheat being the most, and whole rice the least, nutritious. The other cereals occupy an intermediate position between these two extremes. . . . In the north of India—North-West Frontier provinces, Punjab, Baluchistan and United Provinces—wheat is the principal cereal grown ; though some rice, barley, maize or millet is also grown. Generally speaking, the races resident in these areas—Pathans (Afridis, Waziris, Bajauris), Punjabis, Sikhs, Baluchis, Rajputs and Paharis—are wheat-eaters. Wheat is the staple article of their dietaries ; the other cereals mentioned being merely adjuncts to it. A large amount of wheat is also grown in parts of Central India, Bombay and the Deccan ; but in general the races resident in these localities, such as the Maharattas, use a diet of mixed cereals—usually wheat and rice. Towards the East, through Bihar to the coast of Bengal, all down the east and west coasts and throughout the Madras Presidency, rice is the principal cereal grown ; though in parts of these regions millet is also a considerable crop. . . .

. . . As we pass from the north to the east, south-east, south-west and south of India there is a gradual fall in the nutritive value of the cereal grains forming the staples of the national diets, this fall reaching its lowest limit amongst the rice-eaters of the east and south. . . . Accompanying this gradual fall in the nutritive values of the national diets there is a gradual decline in stature, body-weight, stamina and efficiency of the people. Indeed, nothing could be more striking than the contrast between the manly, stalwart and resolute races of the north—the Pathans, Baluchis, Sikhs, Punjabis, Rajputs and Maharattas —and the poorly developed, supine and toneless peoples of the east and south : Bengalis, Madrassis, Kanarese and Travancorians."

Further evidence of the health-giving properties of the wheat diet

in India is afforded by the observations of Balfour and Talpade (81). A survey of the diets of pregnant women indicated that the consumption of fat, protein and vitamins was much higher in North than in South India, though the calorie value of the diet was about equal. It was found that in 16 cases of women in the North who had borne premature infants only two had taken their usual nutritious diet during pregnancy. The change in the diet, which took place half-way through pregnancy, was largely one from wheat to rice, and caused a sudden fall in the consumption of vitamin B_1. Additional evidence also confirmed that the greater the proportion of wheat or bajri in the diet the less the tendency to prematurity or to weakly infants.

It must not be thought that the striking association between the diminishing nutritive value of the staple food and the lowered physical development observed by McCarrison in Indian races is wholly determined by the type of cereal consumed. While he emphasizes the important part played by cereals, McCarrison also draws attention to corresponding changes in the other constituents of the diet which assist in bringing about this result. In fact it so happens that as the nutritive values of the cereal grains diminish from the north to the south of India there is also a diminution in the amount of animal protein, animal fat and milk entering into the native dietaries studied. This again illustrates the fallacy of considering the nutritive value of cereals apart from the other constituents of the diet.

IV. Summary and Conclusions.

Since the dawn of history wheat has been the staple foodstuff of the most advanced civilisations. Its importance as a bread grain outstrips that of all other cereals, a fact which largely depends on taste, custom, æsthetic appeal and price. Considered apart from the other constituents of a diet, its nutritive value is not less than that of barley, oats or rye and almost certainly exceeds that of maize and rice. As with all cereals, the nutritive importance of wheat lies primarily in its fuel value, and a diet which includes wheat is imperfect unless it contains in addition suitable proportions of milk, butter, meat, vegetables and fruits to supply essential dietary constituents lacking in wheat. From our study of the relationship between wheat consumption and disease the chief impression left on the mind is that wherever we find communities subsisting on adequate diets, including milk, fruits, vegetables and

other protective foods, there also, as a general rule, is wheat the staple cereal. In such conditions disease due to faulty nutrition does not bulk largely as a public health problem. In contrast to this, beriberi, scurvy, pellagra and other diseases are notoriously prevalent among peoples accustomed to exist on rice, maize and other low-grade cereal diets, especially when through ignorance, indifference or lack of opportunity the deficiencies inherent in such diets remain uncorrected by the use of protective foods.

Finally a word should be said on the possibility of increasing the human consumption of wheat throughout the world. Is it desirable to urge an increased consumption ? It is obvious that the question will apply differently to different peoples. There is no nutritional reason for advocating increased consumption among the advanced peoples of European and North American countries, who already consume large quantities of wheat. Indeed there is much evidence pointing to the desirability of diminished consumption of wheat in favour of increased consumption of protective foods such as milk, butter and eggs. Is it not precisely in this very consideration that the answer to the question lies ? As an outlet for surplus wheat it would be infinitely more in the interests of public health to press for its increased use as a feed for stock, thus converting it into the nutritionally superior commodities milk, butter, eggs and meat, than to encourage its increased consumption in the form of wheaten bread.

In countries where maize and rice are the staples the case is different. Probably in no country in the world at the present time does one article of food represent so large a proportion of its total food supply as does rice in Japan—a circumstance which undoubtedly gives rise to much ill-health. Rice contains less protein than other cereals, and even if protective foods are used it is difficult to believe that the use of so much rice can be anything other than detrimental to health. To alter the traditional dietary habits of rice and maize-eating peoples in the direction of a greater use of wheat is, however, a matter of great complexity. Such a change can be accomplished only very gradually, and is to a considerable degree dependent on raised standards of living following improvement in economic conditions. In Morocco, according to Gaud (82), increase of prosperity brings about a rise in the consumption of wheat at the expense of barley ; and, as we have already mentioned (7), signs are not lacking that wheat is finding increasing favour among typical rice-eating peoples of the East. The results of such tendencies may be of the highest importance not only in relation to

the health of peoples but also in their reactions on the world wheat markets, at present suffering from the embarrassments of over-production.

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